MEASUREMENT OF THE ANALYZING POWER OF PROTON-CARBON ELASTIC SCATTERING IN THE CNI REGION AT RHIC

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The proton-carbon elastic scattering process in the Coulomb Nuclear Interference (CNI) region at very low momentum transfer $-t$, is used to measure the polarization of the proton beam in the relativistic heavy ion collider (RHIC) at Brookhaven National Laboratory (BNL). In 2004, the p-carbon process has been calibrated for the first time using a polarized Hydrogen gas jet target at two RHIC energies (24 GeV, 100 GeV). The transverse single spin asymmetry, A_N, of p-carbon elastic scattering were measured with good precision as a function of $-t$ over a wide domain. The results were fit with theoretical models which allows the contribution from hadronic spin flip amplitude.

Elastic scattering process of polarized proton off the nucleus at RHIC energies ($24 - 250$ GeV/c^2) carry an interesting information on spin dependent hadronic spin-flip amplitude, and has a very important role in RHIC polarimetry. At small momentum transfer region called Coulomb-Nuclear Interference (CNI), i.e. $0.005 < -t < 0.05$ (GeV/c)^2 where $t = (p_{out} - p_{in})^2 \approx -2M_C T_{kin} < 0$, the single transverse spin asymmetry, A_N, of p-carbon elastic process is currently used for proton polarization measurement in RHIC. The data gives a good opportunity to extract the physics information on the hadronic contribution. At very small angle scattering, the elastic process dominates, and experimentally the elastic events are clearly identified by measuring the recoil carbons in the polar angles around 90° at laboratory frame. In CNI region, the electromagnetic and hadronic helicity amplitudes become a comparable size. The A_N arises mainly from the interference between the coulomb spin-flip amplitude (which is responsible for the anomalous magnetic moment of the proton) and hadronic non spin-flip amplitude. This interference term, called 'pure CNI' is precisely determined from QED calculation. However there is the other interference term having a contribution from hadronic spin flip amplitude (coupling with coulomb non spin-flip amplitude), which is described by the Regge poles exchange phenomenology[1]. Since this is about the non-perturbative QCD effect, experimental data is indispensable. Following the analogy to the helicity amplitude formalism of proton-proton elastic scattering, pC process can be described by two amplitudes, spin non flip $F_{+0}(s,t)$, and spin flip amplitude $F_{-0}(s,t)$. The spin flip amplitude parameter $r_5^{pC}(t)$ is defined as, $r_5^{pC}(t) = mF_{-0}^h/(\sqrt{-t}\ \mathrm{Im}F_{+0}^h)$, where m is the proton mass, and $F_{\pm 0}^h$ is the hadronic element of the helicity amplitudes. This is translated to t independent parameter r_5 for pp with simple formula[7]. The E950[2] has been the only measurement so far measured $A_N^{pC}(t)$ at 21.7 GeV/c. The r_5 result from E950 was about 15% and strong correlation was seen between real and imaginaly parts. For the RHIC pC CNI polarimeter, polarized proton beam passes through an ultra-thin carbon ribbon target (3.5-$\mu g/cm^2$ thick[3]), and carbon recoils from CNI scattering are observed in six silicon strip detectors placed at 90° to the beam direction, 15cm away from the target. Each detector has $10 \times 24mm^2$ active area divided into 12 strips, each directed to the beam line. The six detectors are mounted inside the vacuum chamber with readout preamplifier boards directly attached to the feed-through connector on the detector ports. Data acquisition is based on the waveform digitizer modules (WFD)[6]. The system enable to readout the data without deadtime to accommodate the very high event rates. The waveforms from strips are digitized, and energy (E) and time of flight (TOF) w.r.t. the RHIC rf clock are determined by on-board FPGA. Typically 2×10^7 samples of carbon events are stored in memory on board and readout after the measurement for the offline data analysis. Slow particles inside our kinematical acceptance follow the non-relativistic kinematics i.e., $TOF = \sqrt{\frac{M_C L^2}{2}}\frac{1}{\sqrt{E}}$, which is slightly deformed by energy loss correction in the inactive silicon surface. The size of deformation is used to estimate the thickness of the inactive layer[4]. The thickness is estimated to be $57 \pm 12\mu g/cm^2$. Invariant mass of the recoil particle is reconstructed with the time and energy information. The three standard deviation cut around

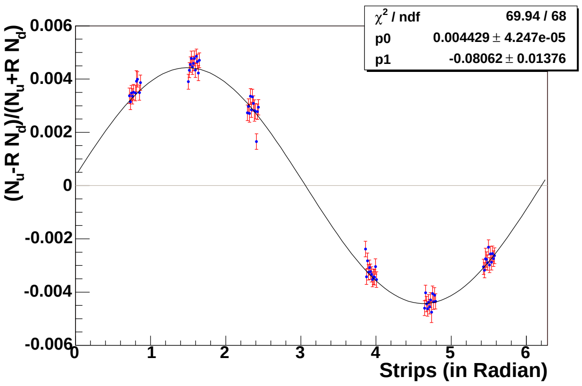

Figure 1. Strip by strip asymmetry measurements. The raw up-down asymmetries are plotted as a function of strip location in radian. The curve is the best fit with the sine function allowing phase shift, i.e. $f(\phi) = P_0 \sin(\phi + P_1)$

the carbon peak is applied for the carbon identification. A raw asymmetry is calculated for carbon counts in left and right detectors using a square root formula, which takes advantage of the altenating spin patterns in RHIC[8]. Since each silicon strip can surve as the indivisual polarimeter, the systematic error of the measurements are estimated from the size of flucturation among the asymmetries for strips. Figure 1 shows the up-down asymmetry for i-th ($i = 1 \cdots 72$) strip ($\equiv (N_i^u - R \cdot N_i^d)/(N_i^d + R \cdot N_i^d)$ where R is the luminosity ratio of up/down spin bunches). By allowing the phase shift to the $\sin\phi$ fit (two parameters: amplitude, phase), the χ^2/ndf is reduced to 70/68, whereas it is 104/69 for one parameter fit. This χ^2/ndf value indicates there is negligible systematic error in the measurement, and possible spin tilt ($4 \sim 5$ degrees) from vertical. The A_N^{pC} is obtained from dividing the raw asymmetry of pC events by beam polarization from Hydrogen gas jet target measurement[5], Figure 2 shows the obtained $A_N^{pC}(t)$ at 100GeV. P_{beam} used for the normalization is, $P_{beam} = 0.386 \pm 0.033$ [5]. Thin line on top of the data points is the best fit result with the model function which allows hadronic spin flip[1]. The error bars on the data points are statistical only. Size of systematic errors is shown with the shaded band. They are due to (i) the $-t$ ambiguity from the uncertainty in inactive surface layer width of silicon, (ii) the error of the beam polarization measured with Jet. As in the fig. 2, r_5 value from the best fit results, Re $r_5 = 0.051 \pm 0.002$ and Im $r_5 = -0.012 \pm 0.009$. The uncertainty is actually large due to the two systematic error sources described above. The 1-σ error contour has a very

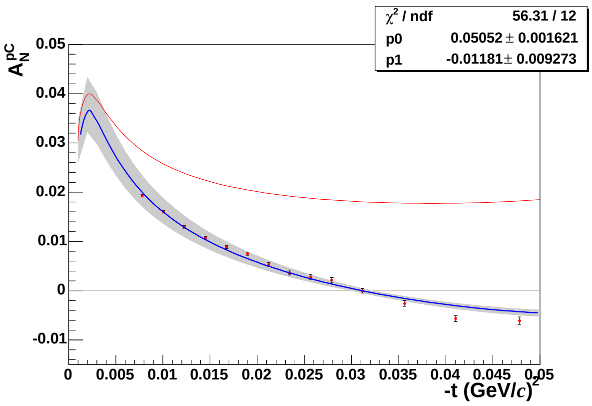

Figure 2. Measured $A_N(t)$ at 100GeV. The calibration is carried out the polarization measured by Jet. The result for best fit using hadronic spin flip model is significantly departed from the zero spin flip calculation (the top curve). The shaded band represents the systematic uncertainty of the measurement

stong anti correlation between real and imaginary part of r_5, starts from $(\mathrm{Re}r_5, \mathrm{Im}r_5)$ = (0.070, -0.16) to (0.035, 0.110). For 24GeV, though the absolute scale of $A_N(t)$ is not available yet, the shape is obtained and compared with 100GeV for the range, $0.008 < -t < 0.028(\mathrm{GeV/c})^2$. The slope of $A_N^{pC}(t)$ at 100GeV is significantly steeper than 24GeV. In summary, the measurement of $A_N(t)$ $(0.008 < -t < 0.05\ (\mathrm{GeV/c})^2)$ for proton-carbon at 100GeV was carried out, in conjunction with the beam polarization measurement by jet-target polarimeter. Also the shapes of $A_N(t)$ at 24GeV, 100GeV were compared, indicated the difference in slopes. The calibration of $A_N(t)$ at 24GeV is under analysis, we will obtain the new result from 24GeV fairly soon.

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